DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY
E11, APRIL 13, 2005

MIDTERM EXAM 2

Name and Student ID: SOLUTION

Instructions: Answer the questions that follow directly on these pages in the spaces provided. Use the back of the page if you need more room for your answer. If you believe there is insufficient information provided to answer a question completely, state reasonable assumptions and proceed from there.

This exam is closed-book/closed-notes. Calculators are not allowed.

Time: 50 minutes.

Question:	Score:	Out of:
1	_____	5
2	_____	6
3	_____	4
4	_____	5
5	_____	3
BONUS	_____	
TOTAL	_____	23

Useful Data and Formulas:

Atomic masses: H=1, C=12, N=14, O=16, S=32 g mol^{-1}

Ideal gas law: $PV = nRT$

Area of circle: $\pi d^2/4$

Surface area of sphere: πd^2

Volume of sphere: $\pi d^3/6$

1. ENERGY CONSUMPTION & AIR POLLUTION

a) List six "criteria" air pollutants regulated by the EPA. (1 point)

CO - carbon monoxide } primary
Pb - lead
SO_2 - sulfur dioxide

O_3 - ozone - secondary
NO_2 - nitrogen dioxide - mainly secondary
PM - particulate matter - primary and secondary
($PM_{2.5}$, PM_{10})

b) In what order do the peak concentrations of nitrogen monoxide, nitrogen dioxide and ozone occur on a typical weekday in Los Angeles? Explain your answer. (2 points)

1. NO, 2. NO_2, 3. O_3

- NO is emitted from cars (combustion), NO_2 and O_3 are secondary air pollutants. NO_2 is formed by the oxidation of NO. VOCs are important for the $NO \rightarrow NO_2$ conversion. NO_2 photolysis drives O_3 formation: $NO_2 + h\nu \rightarrow NO + O^\cdot$ } photolysis yields the oxygen radical that combines w/ molecular oxygen
$O^\cdot + O_2 \rightarrow O_3$ }

c) State two reasons why there are two air quality standards for particulate matter. (1 point)

There are two PM standards: $PM_{2.5}$, PM_{10}

- Fine ($PM_{2.5}$) and coarse (PM_{10}) particles have different formation mechanisms (ie, different sources) and thus have different chemical composition and require different control strategies.
- Fine PM penetrates more deeply in respiratory system than coarse PM_{10}

d) Explain the difference between the lower and higher heating values of a hydrocarbon fuel. (1 point)

- HHV > LHV
- The difference between the two is the state of H_2O in the combustion products
- HHV is calculated assuming that H_2O vapor condenses to H_2O liquid, which releases the latent heat of vaporization
- LHV - H_2O is assumed to remain in the vapor phase

2. COMBUSTION STOICHIOMETRY

a) Write a balanced reaction for the stoichiometeric combustion of ethene (C_2H_4) in pure oxygen. (1 point)

$$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$$

b) Calculate the oxygen/fuel mass ratio for the above reaction (you can express your answer as a fraction with valid units explicitly shown). (1 point)

$$\frac{3\text{ moles } O_2}{1\text{ mole } C_2H_4} \cdot \frac{1\text{ mole } C_2H_4}{28\text{ g } C_2H_4} \cdot \frac{32\text{ g } O_2}{\text{mole } O_2} = \frac{96}{28}\ g_{O_2}/g_{C_2H_4}$$

c) Calculate the gross heat of combustion (kJ/mol) for ethene given the enthalpies of formation (kJ/mol) for the following compounds: (2 points)
$C_2H_4 = 50$, $O_2 = 0$, $CO_2 = -400$, $H_2O(l) = -300$

$$\Delta h = 2\Delta h_{f,CO_2} + 2\Delta h_{f,H_2O} - [3\Delta h_{f,O_2} + \Delta h_{f,C_2H_4}]$$

$$= -800 + -600 - \phi - 50\ kJ/mol$$

$$= -1450\ kJ/mol$$ ⊖ sign indicates exothermic rxn.

d) Calculate the carbon intensity, CI, of ethene (you can express your answer as a fraction with valid units explicitly shown). (2 points)

CI is the mass of carbon emitted per MJ energy content

$$CI = \frac{2\text{ moles } CO_2}{\text{mole } C_2H_4} \cdot \frac{1\text{ mole } C}{1\text{ mole } CO_2} \cdot \frac{12\text{ g } C}{\text{mol } C} \cdot \frac{\text{mol } C_2H_4}{1450\text{ kJ}} \cdot \frac{1000\text{ kJ}}{MJ}$$

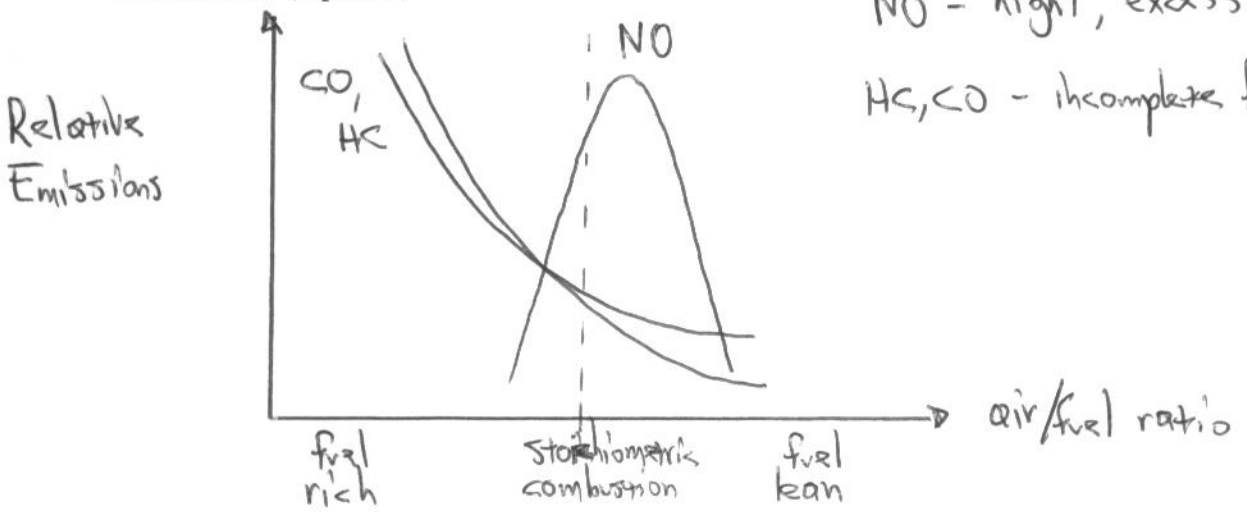
$$CI = \frac{24}{1.45}\ g_C/MJ$$

3. MOTOR VEHICLE EMISSIONS

a) Sketch a graph of pollutant emissions versus air/fuel mass ratio for CO, HC and NO, and indicate the parts of the plot that correspond to fuel rich, fuel lean, and stoichiometeric combustion. (2 points)

NO - hight, excass air (O_2)

HC, CO - incomplete fuel combustion



b) In regards to combustion stoichiometry, explain how oxygenated gasoline reduces pollutant emissions from cars. (1 point)

Oxygenated gasoline contains oxygenated compounds (e.g., ethanol, MTBE). Using oxygenated gasoline adds oxygen to the engine air/fuel mixture. Improperly tuned engines that run "fuel rich" should emit less HC, CO when using oxygenated gasoline because it "leans out" the air/fuel mixture.

c) What have remote sensing measurements of vehicular pollutants indicated about the distribution of emissions among vehicles? (1 point)

The emissions distribution is skewed: ~ 50% of pollutants (CO, HC, NO_x) are emitted by ~10% of vehicles.

4. CLIMATE CHANGE

a) Which greenhouse gas has the largest radiative forcing per unit mass, carbon dioxide, methane or nitrous oxide? (1 point)

N_2O - nitrous oxide

b) Explain two reasons why the radiative forcing of carbon dioxide is known with greater certainty than the radiative forcing of black carbon. (1 point)

1. Optical properties (i.e., how they interact w/ sunlight) are better known for CO_2 (and all greenhouse gases) than BC (and all aerosols)

2. Atmospheric concentrations are spatially and temporally variable for BC due to its short atmospheric lifetime (~ weeks in troposphere) CO_2 concentration is homogeneous throughout atmosphere due to long lifetime (~ centuries).

c) Explain two ways in which sulfate aerosols perturb the earth's radiation balance with space. (1 point)

1. Directly by scattering sunlight back to space

2. Indirectly by altering cloud albedo and lifetime - by serving as cloud condensation nuclei.

d) How do scientists reconstruct the historical record of atmospheric carbon dioxide and methane concentrations? (1 point)

Analysis of gas bubbles trapped in ice cores.

e) Write an expression for rate at which the earth absorbs solar energy (W) in terms of the earth's albedo, α, and diameter, d (m), and the solar constant, S ($W\ m^{-2}$). (1 point)

$$S(1-\alpha)\frac{\pi d^2}{4}$$

5. WATER TREATMENT

a) In drinking water treatment, what two processes precede the sedimentation basin to improve the particle collection efficiency in the basin? (1 point)

Coagulation - addition of coagulant chemicals w/ efficient mixing

flocculation - gentle mixing to promote "soft" particle collisions and floc formation.

b) Name three treatment options intended to control for pathogens in water? What treatment option offers protection against contamination in the water distribution system? (1 point)

UV

O_3

Chlorine } offer residual protection against pathogens
Chloramine } that may contaminate treated water in the water distribution system.

c) Explain the purpose of primary and secondary standards in water treatment? (1 point)

Primary - protection of human health
- make water safe to drink

Secondary - favorable characteristics of:
i) aesthetics (color, taste, clarity, odor)
ii) corrosivity
iii) hardness

BONUS QUESTIONS (0.5 point each)

i) Write the third reaction in the primary photolytic cycle.

$$NO + O_3 \longrightarrow NO_2 + O_2$$

ii) Where did Dr. Chu conduct the research that led to his 1997 Nobel Prize in physics?

Bell Labs

iii) Do you plan to attend Monday's (optional) field trip to the landfill? (circle one, credit given for either answer)

Yes No